Arizona Department of Transportation

WORKBOOK

for

SUBGRADE AND BASE COURSE INSPECTION (Course Number 104)

a training course developed
for the

ARIZONA DEPARTMENT OF TRANSPORTATION
Phoenix, Arizona

by

ROY JORGENSEN ASSOCIATES, INC.
Gaithersburg, Maryland

Revised by ADOT – July 1, 2002

WORKBOOK

for

SUBGRADE AND BASE COURSE INSPECTION (Course Number 104)

a training course developed
for the

ARIZONA DEPARTMENT OF TRANSPORTATION
Phoenix, Arizona

by

ROY JORGENSEN ASSOCIATES, INC.
Gaithersburg, Maryland

Revised by ADOT – October 20, 2006

Table of Contents

Directions To Workbook Users

Subgrade and Base Course Inspection (Course 104) is one in a series of courses on inspection and quality control for earthwork construction. Other courses in the series include:

- Field Sampling and Testing for Earthwork (Course 101),
- Excavation and Embankment Inspection (Course 102),
- Pipe Placement Inspection (Course 103), and
- Incidentals Inspection (Course 105).

This course is designed primarily for highway construction inspection personnel, but it can also be used in training other personnel.

This workbook is to be used in conjunction with discussion sessions with the trainee's instructor or supervisor, and other materials that make up the course. As sections of this Workbook are assigned, each trainee should:

1. read and study the material to review previously presented information and gain additional details;
2. complete the exercises and quizzes as they are provided;
3. check his answers against those provided following the exercise or quiz;
4. review the material as needed to correct and clarify any incorrect answers; and
5. discuss any areas that are still not clearly understood with his instructor or supervisor.

Each trainee should be provided with his own copy of this Workbook so that he can write in it and keep it for future reference and review.

This course is based primarily on the following sections of ADOT's *Standard Specifications for Road and Bridge Construction*:

- 203 – Earthwork: Untreated Subgrades Finishing,
- 301 – Lime-Treated Subgrade,
- 302 – Cement-Treated Subgrade,
- 303 – Aggregate Subbases and Aggregate Bases,
- 304 – Cement-Treated Base, and
- 305 – Lean Concrete Base.

Also, the following sections of the ADOT's *Construction Manual* provided information for this course:

- Earthwork: Untreated Subgrades Finishing,
- 301 – Lime-Treated Subgrade,
- 302 – Cement-Treated Subgrade,
- 303 – Aggregate Subbases and Aggregate Bases,
- 304 – Cement-Treated Base,
- 305 – Lean Concrete Base, and
- 1203 – Inspection of Base Materials.

Notes

First Discussion Period
(Introduction)

Section One: Subgrade Construction

Introduction

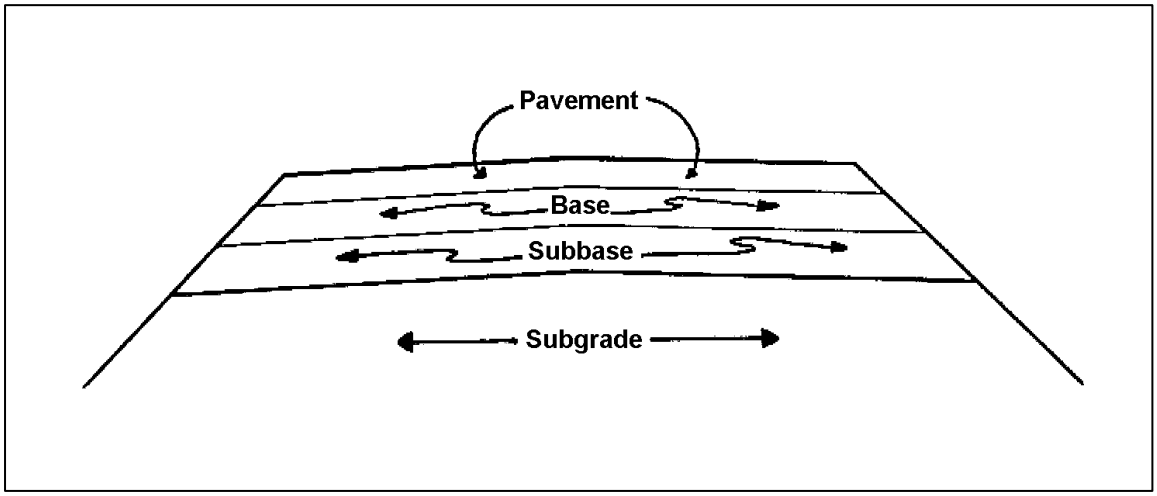
Generally, a roadway is made of several different horizontal layers or courses which include a subgrade, a subbase, a base and a wearing course. Please refer to the illustration as we discuss each of these courses.

The subgrade is the top surface of the roadway embankment although it is underneath the base courses. It is the thickest layer of the roadway itself. Subgrades are made of untreated, lime-treated or cement-treated materials.

The base course is usually formed between the subgrade and the wearing courses. Sometimes, a subbase course is found between subgrade and the base courses. Bases and subbases are made of aggregate, cement-treated, or lean concrete materials.

The pavement is the top layer(s) of the roadway. For our purposes, it can be made of concrete, chip seal, or asphalt concrete. This course includes detailed information on subgrade, subbase and base inspection. For information on pavement inspection, refer to:

- Concrete Paving Inspection (Course 203),
- Chip Seal Coat Inspection (Course 303), and
- Asphalt Paving Inspection (Course 305).



Untreated Subgrade

Untreated subgrade is found in excavated areas and embankment areas. The guidelines for subgrade operations are different for each of these two areas.

All roadway excavation shall be finished to a reasonably smooth and uniform surface and shall not vary by more than 0.04 foot above or below the established grade and shall be in reasonably close conformance to the lines, dimensions, and cross sections shown on the project plans or established by the Engineer.

When Portland Cement Concrete Pavement or Asphaltic Concrete Pavement are to be placed directly on the Subgrade, the finished surface shall not vary by more than 0.02 foot above or 0.04 foot below the established grade. When roadway excavation is made in rock, the full cross section width of the roadway between the ditches shall be over excavated a minimum depth of six inches below the subgrade elevation.

The over-excavated area shall be filled with embankment material satisfactory to the Engineer and compacted and finished in accordance with the requirements of the *Standard Specifications*. In situations where only part of the roadway section intersects areas of rock, that portion occurring in the rock zone shall be over-excavated and backfilled as noted above and brought up to match the adjoining subgrade.

The top six inches of the subgrade shall be compacted to a density of not less than 95 percent of the maximum density, except that when asphaltic concrete or portland cement concrete is to be placed directly on subgrade, the required density shall be 100 percent of the maximum density.

Lime-Treated Subgrade

Before lime-treating operations begin, the contractor must submit a detailed safety program on the handling of the lime. It must state how safety protection will be provided for workers and the general public. This safety program must include provisions for protection to eyes, mouth, nose, and skin. A required first-aid kit must contain an eye wash.

When lime is being hauled to the work site, a Certificate of Compliance and a certification of the shipping weight for each load must be submitted to the Engineer.

Water which will be mixed with the lime and subgrade must be free from harmful amounts of oil, acid, alkali, clay, vegetable matter, silt, or other harmful matter. Bituminous material to be used for curing must be medium curing liquid asphalt, MC-250 or MC-800. For further information regarding regulations for bituminous material, refer to Section 1005 in the *Standard Specifications for Road and Bridge Construction*.

Several roadbed preparations are to be made when placing lime-treated subgrade. In-place material to be lime-treated must be scarified and broken up to the full roadway width and contain no rocks larger than 2-½ inches. If this material has to be windrowed to pass through the mixing machine, keep the windrow small so all of it can be mixed with the lime in a single pass.

When spreading the lime, the application rate must not vary more than 10 percent of the specified rate stated in the special provisions. Do not spread nor mix lime or lime-treated materials when:

- the subgrade is frozen, the air temperature is less than 40° F in the shade, or
- the air temperature may fall below 40° F within twenty-four hours.

Limit the mixing and spreading operations to what can be completed in a working day. Only allow water trucks and mixing equipment to pass over the spread lime before it is mixed.

To mix the lime with the subgrade, use a traveling pugmill or a transverse shaft mixer which has been approved by the Engineer. The moisture in the mixture must be within 2 percent of the optimum moisture level for the material being treated. The treated mixture must be free from streaks or pockets of lime and must contain no more than 5 percent of untreated dirt clods larger than one inch in diameter. Before compaction, the treated mixture must be allowed to cure 24-48 hours to allow chemical reaction to take place. This curing period, along with drying out of the material, may require additional water to be added so that the material will still be within 2 percent of the optimum moisture level prior to compaction.

Spread and compact the treated mixture to the required width, grade and cross-section stated in the project plans. The compacted layers must be equally thick; no more than eight inches each. Each layer of this placed, treated mixture must be compacted to 100 percent of its maximum density. For initial compaction, use a sheepsfoot roller or a grid roller. For final compaction, use a steel-wheeled roller or a pneumatic-tired roller. If asphalt is to be placed directly on the compacted, lime-treated subgrade, the finished surface must not vary more than 0.02 above or .04 below the desired grade.

Each compacted layer must be kept moist until the next layer or the bituminous curing seal is applied. Place the curing seal as soon as possible after the compaction has been completed and before the temperature falls below 35° F. Be sure to keep all traffic off the subgrade for three days after the curing seal has been placed. The contractor is responsible for any damage resulting from negligence.

Cement-Treated Subgrade

When treating subgrade with cement, you must use approved cement, water, and a bituminous curing seal. The subgrade material will already be in place. The water must be free from harmful amounts of oil, acid, alkali, clay, vegetable matter, silt, or other harmful matter. The bituminous curing seal is MC-250 or MC- 800; both are medium-curing liquid asphalt.

To prepare the roadbed for cement-treating the subgrade, scarify and break up in-place material. No rocks should be larger than 2-½ inches in any dimension. If the subgrade material must be windrowed to pass through a mixing machine, keep the windrow small so the subgrade can be mixed with the cement in a single pass.

When adding cement to the subgrade material, the application rate must not vary more than 10 percent of the rate specified in the Special Provisions. Do not spread the cement or cement-treated material if:

- the soil is frozen, the air temperature is less than 40° F in the shade, or
- the air temperature may fall below 40° F within 24 hour hours.

Undertake no more work than can be completed by the end of a one-half work shift. Do not allow traffic, other than water trucks and mixing equipment, to pass over spread cement until it has been mixed with the subgrade.

To mix the spread cement with the subgrade, use an approved traveling pugmill or a transverse shaft mixer. The moisture level in the completed mixture must be within 2 percent of the optimum moisture level for the subgrade material. The cement and subgrade must be mixed until it is uniform (with no cement balls), and has the required moisture.

When compacting the completed mixture, use a sheepsfoot roller or a grid roller to complete the initial compaction no more than two hours after water has been added to the cement and subgrade. After the trimming has been completed, use a steel-wheeled roller or a pneumatic tire roller for final compaction of the subgrade within 2-½ hours after the water has been added The compacted layers must be equally thick with a maximum thickness of no more than eight inches for each.

The layers also must be compacted to 100 percent of their maximum density. Finish the surface according to the specifications in the project plans or as otherwise specified by the Engineer. The finished surface must not vary more than 0.04 foot above or below the desired grade.

When curing cement-treated subgrade, keep the surface moist until the curing seal is placed. Apply the curing seal as soon as possible on the same day final compaction is completed. Keep all heavy traffic equipment off cement-treated subgrade for at least three days; light construction traffic is permissible after the curing seal has been placed. Any resulting damage is the responsibility of the contractor.

If at least four inches of aggregate base will be placed over cement-treated subgrade, it may be used as a curing seal in lieu of the bituminous curing seal. In this case, keep the aggregate base moist for at least 72 hours. This area may be opened to traffic immediately after the aggregate base is placed and compacted.

Section One Quiz

1. For subgrade operations in an excavated area, how much must be compacted to 95 percent of its maximum density? (Circle one)

   a. each layer
   b. the top six inches
   c. the top eight inches
   d. all of the material

2. The subgrade in an embankment area must be compacted to ... (Circle one)

   a. 95 percent of its maximum density.
   b. 100 percent of its maximum density.

3. What should be used as the curing agent for lime-treated subgrade? (Circle one)

   a. lime
   b. RC-150 or RC-800
   c. MC-250 or MC-800

4. Lime-treated materials cannot be mixed or spread if ... (Circle one or more)

   a. the subgrade is frozen.
   b. the wind is blowing in excess of 25 miles per hour
   c. the air temperature is less than 40° F
   d. the air temperature may fall below 40° F within 24 hours.

5. Limit the lime-spreading operations to what can be completed in … (Circle one)

   a. ½ work shift.
   b. one working day.
   c. 24 hours.

6. Limit the cement-spreading operations to what can be completed in … (Circle one)

   a. ½ work shift.
   b. one working day.
   c. 24 hours.

7. For final compaction of a lime-treated subgrade, use a ... (Circle one or more)

   a. sheepsfoot roller.
   b. grid roller.
   c. steel-wheeled roller.
   d. pneumatic-tired roller.

8. When must the curing seal be placed on a cement-treated subgrade? (Circle one or more)
    a. within two hours
    b. within 2-½ hours
    c. as soon as possible
    d. on the same day

Section One Quiz Answers

1. b. the top six inches

2. a. 95 percent of its maximum density

3. c. MC-250 or MC-800

4. a. the subgrade is frozen
   c. the air temperature is less than 40° F
   d. the air temperature may fall below 40° F within 24 hours

5. b. one working day.

6. a. ½ working shift.

7. c. steel-wheeled roller.
   d. pneumatic-tired roller.

8. c. as soon as possible
   d. on the same day

Section Two: Aggregate Bases And Subbases

Aggregate Bases and Subbases

Aggregate used in base and subbase construction falls into six different classes. Each of these classes is based on the percentage of aggregates found within the given class passing through the different sieves. Classes 1-3 of aggregate are used for base construction. Classes 4-6 are for subbase construction. For further information on this classification, refer to Section 303 in the *Standard Specifications for Road and Bridge Construction.*

Before placing the material, add approved water to the aggregate and mix to a uniform blend. The material is placed in uniform layers, with each layer not to exceed six inches. Each layer must be compacted to 100 percent of its maximum density.

The placed material must meet specified tolerances. The finished surfaces must not vary more than these tolerance values for each of the classifications (unless pavement is applied to finish grade).

Classifications	Tolerances
Class 1 Aggregate Base	0.04 foot
Classes 2, 3 Aggregate Base and Class 4 Aggregate Subbase	0.04 foot
Classes 5, 6 Aggregate Subbase	0.04 foot

Compacted aggregate base and subbase must always be ready to receive additional subbase, base, surfacing material, or traffic when so required. Areas beyond tolerances must be corrected by scarifying placed-aggregate base or subbase material, placing additional material, remixing, reshaping, and compacting it again to the specified density and tolerance.

Cement-Treated Base

The proper materials must be used to prepare a cement-treated base. Use Class 2 aggregate, approved cement and water and medium-curing liquid asphalt, MC-250 or MC-800.

The Engineer must approve the job mix design before work gets under way. A new job mix design must be submitted and then approved by the Engineer each time the contractor wants to change it. The approved job mix must specify at least 165 pounds of cement per cubic yard. Also, this mix must reach a minimum compressive strength of 500 pounds per square inch within seven days.

In preparation for placing a cement-treated base, the subgrade on which it will be placed must meet surface finish and tolerance requirements. Also, the subgrade must be free of loose or extraneous materials. Soft areas in the subgrade must be corrected before placing the cement-treated base.

Some general requirements, as well as some specific requirements, must be followed when mixing the aggregate with the cement. Generally, the aggregate and cement must be mixed in a central mixing plant unless otherwise specified. The moisture level of the completed mixture must be within 2 percent of the optimum moisture level for the material. The cement must be evenly mixed with the aggregate. For uniform mixing, do not overload the mixing plant.

Batch mixers must have adequate paddles to produce a uniform mix and an accurate timing device to control the mixing period. Begin the mixing time when the mixer is full and stop when it is half full. Mix the cement and aggregate for at least thirty seconds. The completed mixture must be uniform and the aggregate must be coated evenly.

If using continuous mixing, the proportions of aggregate and cement must be accurate. The control system must have an automatic cut-off in case material in any of the storage facility approaches strike-off capacity. Samples also must be easily obtained.

To spread this completed mixture, use spreader boxes, finishing machines or motorgraders. If one spreader is used alternately on two or more lanes, allow no more than thirty minutes to elapse between placing the mixture in adjacent lanes. The material shall be spread full depth in one pass unless otherwise specified. Do not mix or place a cement-treated base if:

- the aggregate or subgrade is frozen, the air temperature is less than 40° F in the shade, or
- the air temperature will fall below 40° F within 24 hours.

Begin the initial compaction operations immediately after the completed mixture is spread. Overlap each pass by 25 percent. The initial compaction must be completed within two hours after water was added to the aggregate and cement. After the initial compaction is completed, use a motorgrader or planing machine to trim the surface according to lines, grades and cross-sections in the project plans. After trimming is completed, start the final compaction operations which must be completed within 2-½ hours after the water was added. The finished surface must not deviate more than 0.03 foot from the bottom of a ten-foot straightedge placed anywhere on the surface in any direction. Also, the finished surface must not vary more than 0.04 foot from the established grade. Keep the finished surface moist until the curing seal is placed.

If construction is delayed more than two hours or is over for the day, make sure the transverse joint is normal to the centerline of the roadbed and that it has a vertical face. When partial width construction of a cement-treated base is under way and the base has been compacted more than one hour, cut back into the placed material to form a clean longitudinal joint. Be sure to moisten the faces of transverse and longitudinal joints before placing adjacent sections.

After placing the curing seal on the compacted cement-treated base, keep all traffic off it for three days. Light construction traffic may be allowed on days four through seven. The contractor is responsible for any damage to the curing seal.

If at least four inches of aggregate base is to be placed directly on the cement-treated base, it may be used as a curing seal in lieu of the bituminous curing seal. Keep the aggregate base moist for at least 72 hours. Open the area to traffic immediately after the aggregate base is placed and compacted.

Lean Concrete Base (LCB)

As with the other types of base and subbase construction, the proper materials must be used to construct lean concrete bases. These materials include Class 2 aggregate base material or a combination fine and course aggregate suitable for Portland cement concrete, approved cement and water, approved admix, and a Type 2, Class A liquid membrane-forming compound for curing.

In preparation of placing the lean concrete base, the subgrade, subbase or base on which it will be placed must meet surface finish and tolerance requirements. The subgrade must be free of loose and extraneous material and it must be kept moist before and during LCB placement. Soft or unyielding material must be corrected before placing the lean concrete base. This base must be constructed using approved slip-form equipment.

A solid-volume mix design must be submitted and approved by the Engineer. If the mix design must be changed at any time, it must be resubmitted and reapproved by the Engineer. The Engineer may request testing samples of lean concrete base from each mix design. If a sample fails the established compressive strength requirements, a new mix design must be submitted. The mix also must have a slump of 4.5 inches or less.

Various weather requirements must be followed when placing a lean concrete base. If it starts to rain, stop the construction before the surface water causes a flow or wash of surface materials. The contractor must provide adequate insulation, as necessary, to maintain the temperature of the surface material above 50° F for at least three days. The temperature of the mixture must not exceed 90° F or go below 50° F before being placed. If the descending temperature drops below 40° F, stop the placement operations. They may resume when the ascending temperature in the shade reaches 35° F.

Placing and finishing lean concrete bases is generally similar to concrete paving. Refer to Section 401-3.03 in the *Standard Specifications for Road and Bridge Construction* for detailed information regarding these requirements. Each pass must be a minimum of 12 feet wide where possible. Finish the concrete to a smooth, floated surface. The finished surface must not vary more than ⅛ inch when checked with a ten-foot straightedge placed in any direction, except across construction joints, where the tolerance is ¼ inch.

Curing operations must start immediately after the surface is finished. Apply the liquid membrane-forming compound to the surface and sides of this base at the minimum rate of one gallon per 100 square feet.

To determine the compressive strength of the placed lean concrete base, take four random sets from each 4,000 sq. yd. (min. 4 per shift). The minimum average compressive strength which is acceptable is 500 pounds per square inch at seven days.

A lean concrete base must be constructed to the specified thickness in the project plans. The Engineer will judge acceptability from the extracted core samples. The core sample holes must be filled with lean concrete base material or other approved material. If the placed lean concrete base is rejected, it must be replaced with material having the correct thickness. After a lean concrete base is placed, allow no traffic on it until it reaches the seven-day compressive strength requirements. If a new lean concrete base is placed next to a previously placed lean concrete base, the paver and work bridges may go on it after three days. When traffic is allowed directly on a lean concrete base, vehicle weight limitations must be strictly enforced. The contractor is responsible for any damage.

Section Two Quiz

1. What is the primary distinguishing characteristic of the different classes of aggregate base material? (Circle one)

   a. percentage of aggregates passing through sieves
   b. the weight of the aggregates
   c. type of aggregates to be used

2. If the surface of a compacted aggregate base is found to be beyond acceptable tolerances, what are the corrective steps to be taken? (Circle one)

   a. place additional aggregate material
   b. scarify the base
   c. reshape and recompact
   d. all of the above

3. If the contractor proposes to change the job mix design, he ... (Circle one)

   a. documents the changes made.
   b. proceeds so as to not hold up the operation.
   c. submits a new job mix design to the Engineer for approval.

4. The mixing time for batch mixing a cement-treated base ends when … (Circle one)

   a. 20 seconds are up.
   b. the mixer is empty.
   c. the mixer is half empty.

5. Why must a continuous mixing system have an automatic cut-off? (Circle one)

   a. in case material in storage facilities approach strike-off capacity
   b. to prevent overmixing
   c. to assure uniform mixing

6. What equipment is used to spread a completed cement-treated base mixture? (Circle one or more)

   a. spreader boxes
   b. sheepsfoot rollers
   c. finishing machines
   d. motorgraders

7. When construction of a cement-treated base is over for the day, the _____ must be normal to the centerline of the roadbed and have a vertical face. (Circle one)

   a. longitudinal joint
   b. transverse joint
   c. vertical joint

8. Who is responsible for damage to the curing seal? (Circle one)

    a. ADOT
    b. Engineer
    c. Contractor
    d. Subcontractor

9. What is used for curing a lean concrete base? (Circle one)

    a. medium-curing liquid asphalt
    b. liquid membrane-forming compound
    c. MC-800

10. Which of the following are weather requirements for placing a lean concrete base? (Circle one or more)

    a. stop operations if the temperature falls below 40° F
    b. the mixture must not exceed 90° F or go below 50° F before being placed
    c. the temperature of the surface must be above 40° F

Section Two Quiz Answers

1. a. percentage of aggregates passing through sieves

2. d. all of the above

3. c. submit a new job mix design to the Engineer for approval.

4. c. the mixer is half empty.

5. a. in case material in storage facilities approach strike-off capacity

6. a. spreader boxes
   c. finishing machines
   d. motorgraders

7. b. transverse joint

8. c. contractor

9. b. liquid membrane-forming compound

10. a. stop operations if the temperature falls below 40° F
    b. the mixture must not exceed 90° F or go below 50° F before being placed

Section Three: Documentation

This section summarizes the documentation involved in inspecting subbase and base construction in terms of:

- measurements as the basis for payment,
- key information and events to be documented, and
- the records and reports used.

Measurements for Payment

The basis of payment for subgrade and base operations is usually on a line-item basis. Although the Special Provisions section identifies specific items, let's look at some typical line items as they apply to these operations:

- **untreated subgrade** – no measure for payment (except as part of roadway excavation and embankment or grading roadway for pavement;
- **lime-treated subgrade** – by tons of lime and square yards of surface;
- **cement-treated subgrade** – by tons of cement and square yards of surface treated;
- **aggregate subbase and base** – measured by cubic yards in place;
- **cement-treated base** – by tons; and
- **lean-concrete base** – by square yards.

Key Information and Events

Some of the key information and events that need to be documented for subgrades and base courses is similar to that of any construction work including:

- **routine information** – such as the type of work being done, the project, the location, the time of the work and the weather; and
- **special events or problems** – including any unusual conditions, instructions to the contractor, rejected work or materials, and corrective actions taken by the contractor.

Other key items of information and events that need to be documented specifically for subgrade, subbase and base operations include:

- results of moisture and density tests;
- which personnel worked on these operations and for what length of time:
  - compacting,
  - excavation,
  - placing base material (aggregate, cement-treated or lean concrete), and
  - placing subgrade material (untreated, lime-treated or cement-treated).

Records and Reports

The principal records and reports used in documenting subbase and base operations are the:

- Daily Diary; and
- Materials Certification.

Your instructor should be able to provide copies of examples of most of these records and reports.

Daily Diary

The Daily Diary serves as both a record and a report of all key events that occur during the day. All Daily Diaries are the property of the Department and serve as the foundation of all construction project records, so they must be maintained neatly and legibly in ink. They are generally a summary of key events and information, but they must provide sufficient detail so that other personnel can get an accurate picture of what happened each day.

The items recorded in the Daily Diary include:

- such routine information as
  - identification of the project,
  - the type of work being done,
  - the location of the work,
  - the times work is started and stopped,
  - weather conditions,
  - any important phone calls or other communications sent or received, and
  - an inventory of the contractor's equipment and personnel resources being
  - used on the work;
- information on any special events or problems encountered such as:
  - any official visitors to the project,
  - unusual conditions that may affect the work,
  - the times and causes of any delays,
  - important discussions with the contractor and any specific instructions or orders given,
  - the rejection of any materials or work including the reasons for the rejection,
  - any changes, adjustments or corrective actions by the contractor, and
  - any other information that may be relevant to any potential disputes or claims; and
- summaries of the subgrade and base work under way or completed during the day including the type and location of any:
  - compacting,
  - excavating,
  - placing base material, and
  - placing subgrade material.

- field notes[1] for subgrade and base construction, used to record detailed technical information including:
  - calculations and diagrams used in such inspection activities as:
    - checking layout and grade controls;
    - checking compressive strength of base material;
    - verifying curing compound application rates; and
    - measuring structural pay quantities.

Materials Certification

The inspector must control all materials used in subgrade and base operations, including:

- Certificates of Compliance and Analysis for Lime,
- weight tickets for lime,
- results of tests performed on samples sent to the lab for proctors, gradation and plasticity or sand equivalents,
- results of field tests to determine thickness in-place
- results of compressive strengths performed on samples sent to the lab, results of field density tests.

[1] Because they are a key part of the Department's permanent record of the work, all field notes must be neat, clear, and accurate.